

CLAIMS

1. A comb drive apparatus, comprising:
 - a first set of comb pairs;
 - a second set of comb pairs coupled to the first set of comb pairs;
 - 5 a stage coupled to the first and second sets of comb pairs;
 - a first plurality of springs interposed between the second set of comb pairs and the stage and between the second set of comb pairs and the first set of comb pairs for movably coupling the second set of comb pairs to the stage and to the first set of comb pairs; and
 - a second plurality of springs interposed between the first set of comb pairs and the stage and between the first set of comb pairs and the second set of comb pairs for movably coupling the first set of comb pairs to the stage and to the second set of comb pairs.
2. The apparatus of claim 1, wherein each spring of said first plurality of springs being disposed in a first orientation and each spring of said second plurality of springs being disposed in a second orientation substantially orthogonal to the first orientation.
3. The apparatus of claim 2, wherein each spring of said first and second pluralities of the springs is a bar.
- 20 4. The apparatus of claim 1, wherein said each comb pair of the first set of comb pairs comprising:
 - a first fixed comb; and
 - a first movable comb being disposed spatially opposite to the first fixed comb.
- 25 5. The apparatus of claim 1, wherein said each comb pair of the second set of comb pairs comprising:
 - a second fixed comb; and

a second movable comb being disposed spatially opposite to the second fixed comb.

6. The apparatus of claim 1, wherein a first actuation force to said first set of comb pairs providing a first displacement to the stage in a first direction, and a second actuation force to said second set of comb pairs providing a second displacement to the stage in a second direction.

7. The apparatus of claim 6, wherein said first actuation force causes a bending of the first plurality of springs while the second plurality of springs being maintained substantially straight to provide said first displacement.

8. The apparatus of claim 6, wherein said second actuation force causes a bending of the second plurality of springs while the first plurality of springs being maintained substantially straight to provide said second displacement.

9. A comb drive apparatus, comprising:

a first set of comb pairs, each said comb pair having a first fixed comb and a first movable comb, the first movable comb including first and second ends being connected by a first support;

a second set of comb pairs coupled to the first set of comb pairs, each said comb pair of the second set of comb pairs having a second fixed comb and a second movable comb, the second movable comb including first and second ends being connected by a second support;

a suspended stage coupled to the first and second sets of comb pairs;

first and second pluralities of first springs, each first spring having a first end and a second end, the first ends of the first plurality of first springs being connected to the suspended stage and the second ends of the first plurality of first springs being connected to the respective second support of the second movable combs, and the first ends of the second plurality of first springs being connected to the respective first movable comb and the second ends of the second plurality of first springs being connected to the respective first end or second end of the second

movable combs, thereby movably coupling the second set of comb pairs to the suspended stage and to the first set of comb pairs; and

first and second pluralities of second springs, each second spring having a first end and a second end, the first ends of the first plurality of second springs being connected to the suspended stage and the second ends of the first plurality of second springs being connected to the respective first support of the first movable combs, and the first ends of the second plurality of second springs being connected to the respective second movable comb and the second ends of the second plurality of second springs being connected to the respective first end or second end of the first movable combs, thereby movably coupling the first set of comb pairs to the suspended stage and to the second set of comb pairs.

10. The apparatus of claim 9, wherein each first and second spring of said first and second pluralities of the first and second springs is a bar.

11. The apparatus of claim 9, wherein said first fixed comb being disposed spatially opposite to said first movable comb.

12. The apparatus of claim 9, wherein said second fixed comb being disposed spatially opposite to said second movable comb.

13. The apparatus of claim 9, wherein said first set of comb pairs providing a first displacement to the suspended stage in a first direction in response to a first electrostatic force, and said second set of comb pairs providing a second displacement to the suspended stage in a second direction in response to a second electrostatic force.

14. The apparatus of claim 13, wherein said first electrostatic force causes a controlled bending of the first and second pluralities of first springs for displacing said first movable combs

while the first and second pluralities of second springs being maintained substantially straight for preventing displacement of said second movable combs.

15. The apparatus of claim 13, wherein said second electrostatic force causes a controlled bending of the first and second pluralities of second springs for displacing said second movable combs while the first and second pluralities of first springs being maintained substantially straight for preventing displacement of said first movable combs.

16. A method for forming a two-dimensional comb drive, comprising:
providing a first set of comb pairs;
providing a second set of comb pairs coupled to the first set of comb pairs;
providing a stage coupled to the sets of first and second comb pairs;
providing a first plurality of springs interposed between the second set of comb pairs and the stage and between the second set of comb pairs and the first set of comb pairs for movably coupling the second set of comb pairs to the stage and to the first set of comb pairs; and
providing a second plurality of springs interposed between the first set of comb pairs and the stage and between the first set of comb pairs and the second set of comb pairs for movably coupling the first set of comb pairs to the stage and to the second set of comb pairs.

17. A micro-electromechanical apparatus, comprising:
first, second, third, and fourth comb drives, the first comb drive being disposed spatially opposite to the second comb drive and the third comb drive being disposed spatially opposite to the fourth comb drive, each comb drive including:
a fixed comb having a first set of fingers;
a movable comb having a first end, second end, support, and a second set of fingers arranged in an interdigitated manner with the first set of fingers; and

first, second, and third springs coupled to the movable comb to said first end, said second end, and said support, respectively, wherein the movable comb being suspended by the first, second, and third springs for providing a displacement thereof relative to the fixed comb in response to an actuating force being applied between the fixed comb and the movable comb.

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18. A micro-electromechanical comb drive, comprising:

first, second, third, and fourth comb drives, the first comb drive being spatially disposed opposite to the second comb drive and the third comb drive being spatially disposed opposite to the fourth comb drive, each comb drive including:

a fixed electrode;

a movable electrode disposed spatially opposite to the fixed electrode; and

a plurality of spring bars coupled to the movable electrode, the plurality of spring bars being selectively oriented responsive to an actuating force being applied between the fixed and movable electrodes.

19. A micro-electromechanical actuator, comprising:

first, second, third, and fourth drives, the first drive being spatially disposed opposite to the second drive and the third drive being spatially disposed opposite to the fourth drive, each drive including:

a fixed portion a movable portion; and

a spring structure formed to suspend the movable portion, the spring structure displaces the movable portion relative to the fixed portion in response to an actuating force being applied between the fixed portion and the movable portion.

20. A two-dimensional comb drive apparatus, comprising:

a set of horizontal comb pairs, each of the horizontal comb pair having a horizontal fixed comb and a horizontal movable comb, the horizontal movable comb including first and second ends being connected by a horizontal support;

5 a set of vertical comb pairs coupled to the set of horizontal comb pairs, each of the vertical comb pair having a vertical fixed comb and a vertical movable comb, the vertical movable comb including first and second ends being connected by a vertical support;

a suspended stage coupled to the sets of horizontal and vertical comb pairs;

10 first and second pluralities of horizontal springs, each horizontal spring having a first end and a second end, the first ends of the first plurality of horizontal springs being connected to the suspended stage and the second ends of the first plurality of horizontal springs being connected to the respective vertical support of the vertical movable combs, and the first ends of the second plurality of horizontal springs being connected to the respective horizontal movable comb and the second ends of the second plurality of horizontal springs being connected to the respective first end or second end of the vertical movable combs, thereby movably coupling the set of
15 vertical comb pairs to the suspended stage and to the set of horizontal comb pairs; and

20 first and second pluralities of vertical springs, each vertical spring having a first end and a second end, the first ends of the first plurality of vertical springs being connected to the suspended stage and the second ends of the first plurality of vertical springs being connected to the respective horizontal support of the horizontal movable combs, and the first ends of the second plurality of vertical springs being connected to the respective vertical movable comb and the second ends of the second plurality of vertical springs being connected to the respective first end or second end of the horizontal movable combs, thereby movably coupling the set of horizontal comb pairs to the suspended stage and to the set of vertical comb pairs.